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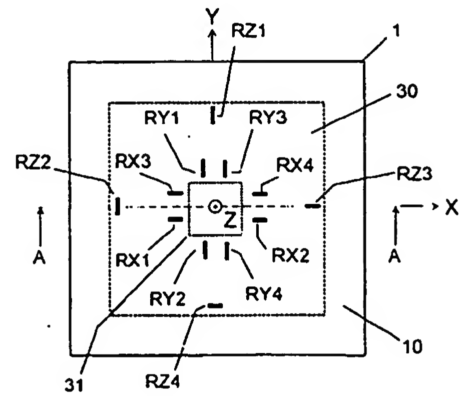
(54) **Acceleration detector.**

(57) In an acceleration detector for detecting three-dimensional components of acceleration applied thereto independently with respect to three axes X, Y and Z of an orthogonal coordinate system, a plurality of piezo resistance elements (RX1-RX4, RY1-RY4, RZ1-RZ4) are formed in a thin-sheet resilient member (30) with an unique arrangement thereof for improving the sensitivity of the detector. Electric resistance of the resistance elements is varied in response to strain of the resistance elements accompanied with an elastic deformation of the resilient member. The resilient member (30) is fixed at its periphery on a frame (10) of the detector (1). A weight is connected with a center portion (31) of the resilient member such that the elastic deformation is caused when the weight is displaced by receiving acceleration. All of the resistance elements for detecting the components of acceleration with respect to the X- and Y-axes are limited within an inner area adjacent to a circumference of the center portion (31). The inner area is capable of causing a larger elastic deformation than the outer area adjacent the frame (10) when the weight is displaced by acceleration. Therefore, an improved sensitivity of the detector is accomplished by the arrangement of the resistance elements.

FIG. 1



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TECHNICAL FIELD

The present invention relates to an acceleration detector which adopts an unique arrangement of resistance elements having a piezo resistance effect for improving the sensitivity thereof.

BACKGROUND ART

As an acceleration detector for detecting acceleration applied thereto, diaphragm- and beam-type acceleration detectors have been already known. For example, as shown in FIGS. 21 and 22, a diaphragm-type acceleration detector **1C** comprises a frame **10C** defining an open space therein and having a top face **11C** and bottom face **12C**, a bottom cover **20C**, a thin-sheet resilient member **30C**, and a weight **40C**. The resilient member **30C** is jointed at its periphery to the top face **11C** of the frame **10C**. The weight **40C** is hung down from a center of the resilient member **30C** through a neck portion **41C**. The neck portion **41C** is fixed with a center portion **31C** of the resilient member **30C** in such a manner as to cause an elastic deformation of the resilient member when the weight **40C** is displaced with respect to the frame **10C** by receiving an acceleration. These parts of the acceleration detector **1C** are made of a semi-conductor material. Resistance elements **R** having a piezo resistance effect are formed in the resilient member **30C** to detect three components of acceleration applied to the detector **1C** with respect to X-, Y- and Z- axes of an orthogonal coordinate system in such a manner that electric resistance of the resistance elements **R** is varied in response to strain of the resistance elements accompanied with the elastic deformation of the resilient member. The acceleration is determined in accordance with a variation of the electric resistance by an acceleration determining section. The bottom cover **20C** is useful as a stopper for preventing a breakage of the resilient member **30C** when receiving an excess acceleration. Numeral "62" designates a bonding pad for wiring a conductor pattern.

U.S. Patent Application No. 4,967,605 discloses an arrangement of resistance elements **R** for a diaphragm-type acceleration detector, as shown in FIG. 24. The resistance elements **R** consisting of a first set of four resistance elements **RX1-RX4** for detecting a first component of acceleration with respect to the X-axis, a second set of four resistance elements **RY1-RY4** for detecting a second component of acceleration with respect to the Y-axis, and a third set of four resistance elements **RZ1-RZ4** for detecting a third component of acceleration with respect to the Z-axis. When X- and Y-axes are set on a plane of a thin-sheet resilient member of the detector, the resistance elements **RX1-RX4** of the first set are aligned on the X-axis, and assembled as a first bridge circuit, as shown in FIG. 25A. The resistance elements **RY1-RY4** of the second set are aligned on the Y-axis, and assembled as a second bridge circuit, as shown in FIG. 25B. In addition, the resistance elements **RZ1-RZ4** of the third set are aligned parallel to the X-axis, and assembled as a third bridge circuit as shown in FIG. 25C. When a predetermined voltage or current is delivered from a power source to each bridge circuit, the respective bridge voltages are measured by voltage meters **Vx**, **Vy** and **Vz**. Therefore, the three components of acceleration can be detected independently with respect to the X-, Y- and Z-axes.

On the other hand, a beam-type acceleration detector **1D** is the substantially same structure as the diaphragm-type acceleration detector except that a resilient member **30D** is formed with four rectangular holes **32D** around a center portion **31D** thereof so as to be shaped into a cross beam configuration, as shown in FIG. 23. In case that the beam-type acceleration detector **1D** adopts the same arrangement of the resistance elements of FIG. 24, stresses received the resistance elements when acceleration is applied to a weight **40D** of the detector are analyzed as below. That is, when no acceleration is applied to the detector, stress is not applied to the resistance elements, as shown in FIG. 26A. For example, when acceleration **F1** is applied to the detector upwardly in the Z-axis direction, as shown in FIG. 26B, each of the resistant elements **RX1**, **RX4**, **RY1**, **RY4**, **RZ1**, and **RZ4** receives a compressive stress $\sigma 1$ which is indicated by minus sign in FIG. 26C. Each of the resistance elements **RX2**, **RX3**, **RY2**, **RY3**, **RZ2** and **RZ3** receives a tensile stress $\sigma 2$ which is indicated by plus sign in FIG. 26C. The tensile stress $\sigma 2$ is equal to the absolute value of the compressive stress $\sigma 1$. Therefore, when acceleration is applied to the detector in the Z axis direction, a sensitivity of the acceleration detector is not dominated by the arrangement of the resistance elements.

However, when acceleration **F2** is applied to the detector in the X-axis direction, as shown in FIG. 26D, each of the resistant elements **RX1** and **RZ1** receives a tensile stress $\sigma 3$, and each of the resistance elements **RX3** and **RZ3** receives a tensile stress $\sigma 4$ which is twice as large as the stress $\sigma 3$. On the contrary, each of the resistance elements **RX4** and **RZ4** receives a compressive stress $\sigma 6$, and each of the resistance elements **RX3** and **RZ3** receives a compressive stress $\sigma 5$ which is twice as large as the stress $\sigma 6$. These compressive stresses are indicated by minus sign in FIG. 26E. The tensile stresses $\sigma 3$ and $\sigma 4$

are respectively equal to the absolute values of the compressive stresses $\sigma6$ and $\sigma5$. In this case, no stress is applied to the resistance elements **RY1** to **RY4**. Though the above analysis is performed with respect to the acceleration having the X-axis direction thereof, the similar results of stress analysis are obtained with respect to acceleration having the Y-axis direction thereof. Consequently, the absolute value of stress received the resistance element adjacent to a frame **10D** of the detector is equal to a half of that of stress received the resistance element adjacent to the center portion **31D** of the resilient member **30D**. This fact indicates that the arrangement of the resistance elements of the prior art results in a low sensitivity of the acceleration detector when acceleration is applied to the detector in the X- or Y-axis direction. The above stress analysis is performed with respect to the beam-type acceleration detector **1D** because a stress analysis of the diaphragm-type acceleration detector **1C** is very complex. However, there is the same problem as the beam-type acceleration detector with respect to the diaphragm-type acceleration detector.

For improving the above problem, the present invention is directed to an acceleration detector for sensitively detecting three-dimensional components of acceleration applied thereto independently with respect to X-, Y- and Z-axes of an orthogonal coordinate system. The acceleration detector comprises a frame defining an open space therein and having a top face and a bottom face, a thin-sheet resilient member extended over the open space and integrally joining at its periphery to the top face of the frame, a weight depended from a center of the resilient member through a neck portion, a plurality of resistance elements having a piezo resistance effect formed in the resilient member. These parts of the acceleration detector are integrally made of a semi-conductor material. The X- and Y-axes are defined to extend in the general plane of the resilient member. The neck portion is fixed with a center portion of the resilient member in such a manner as to cause an elastic deformation of the resilient member when the weight is displaced with respect to the frame by receiving the acceleration. Electric resistance of the resistance elements is varied in response to strain of the resistance elements accompanied with the elastic deformation of the resilient member. The resistance elements consist of a first set of four resistance elements for detecting a first component of the acceleration with respect to the X-axis, a second set of four resistance elements for detecting a second component of the acceleration with respect to the Y-axis, and a third set of four resistance elements for detecting a third component of the acceleration with respect to the Z-axis. All of the resistance elements of the first and second sets are limited within an inner area of the resilient member independently adjacent to a circumference of the center portion. The inner area is capable of causing a larger elastic deformation than an outer area of the resilient member adjacent to the frame when the weight is displaced by receiving the acceleration. Consequently, the acceleration is determined by an acceleration determining section of the acceleration detector in accordance with a variation of electric resistance of the resistance elements.

Therefore, it is a primary object of the present invention is to provide an acceleration detector which adopts an unique arrangement of resistance elements having a piezo resistance effect for sensitively detecting three-dimensional components of acceleration applied thereto independently with respect to X-, Y- and Z-axes of an orthogonal coordinate system.

In a preferred embodiment of the present invention, the resistance elements of the third set are formed in the resilient member such that two resistance elements are arranged at opposite positions of the outer area on the X-axis and the other two resistance elements are arranged at opposite positions of the outer area on the Y-axis.

It is further preferred that the four resistance elements of the third set are aligned on one of the X- and Y-axes.

It is still further preferred that the four resistance elements of the third set are also arranged within the inner area.

In another preferred embodiment, the acceleration detector includes the following structural features for effecting as a beam-type acceleration detector. That is, the resilient member is formed with four rectangular holes around the center portion so as to be shaped into a cross beam configuration. An upper cover is fixed on the top face of the frame in a spaced relation to the resilient member. The weight is formed integrally with four projections which project respectively into the rectangular holes in such a manner that a top face of each projection is flush with the top surface of the resilient member. A corner of each projection is merged integrally to the center portion of the resilient member by way of a joint portion.

When the acceleration detector has the above explained structural features, it is preferred that it further comprises upper and lower electrodes for determination of the acceleration in a self-checking manner. The upper electrode is mounted on at least one of the projections of the weight. On the other hand, a lower cover is fixed on the bottom face of the frame in a spaced relation to the weight. The lower electrode is mounted on a bottom surface of the weight in a facing relation to a top surface of the lower cover. The upper and lower electrodes are respectively adapted to apply voltage differences between the upper cover

and the upper electrode, and between the lower electrode and the lower cover to develop electrostatic forces in order to displace the weight with respect to the frame. The joint portion is adapted to form a conductor pattern from the upper electrode to a voltage supply.

In particular, the upper electrode consists of a rectangular plate and two triangular plates which are so arranged as to give a generally triangular configuration of the upper electrode as a whole, and the lower electrode is in the form of a triangular configuration. The upper and lower electrodes are horizontally offset such that the resulting two electrostatic forces are cooperative to displace the weight along the X-, Y-, and Z-axes simultaneously.

Other features, objects and advantages of the present invention will become more apparent from the following description and attached drawings about the preferred embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows an arrangement of resistance elements of an acceleration detector of a first embodiment of the present invention;

FIG. 2 is a perspective view of the acceleration detector, which is cut away by the line A-A of FIG. 1

FIG. 3 is an enlarged cross-sectional view of the resistance element RZ3 of FIG. 2;

FIGS. 4A and 4B show arrangements of resistance elements **RX1-RX4** of the prior art and the present invention, respectively;

FIG.5 is a perspective view illustrating a position of an electrode mounted on a weight of the detector;

FIG. 6 is a perspective view illustrating positions of another electrodes mounted on the weight;

FIG. 7 shows an arrangement of resistance elements of a second embodiment of the present invention;

FIG. 8 shows an arrangement of resistance elements of a third embodiment of the present invention;

FIG. 9 shows an arrangement of resistance elements of a fourth embodiment of the present invention;

FIGS. 10A to 10C are exploded perspective views of a beam-type acceleration detector of a fifth embodiment of the present invention;

FIG. 11 is a top plane view of the acceleration detector of the fifth embodiment;

FIG. 12. is a cross-sectional view of the acceleration which is taken along the line B-B of FIG. 11;

FIGS. 13A to 13C are exploded perspective views of a beam-type acceleration detector of a sixth embodiment of the present invention;

FIG. 14 is a top plane view of the acceleration detector of the sixth embodiment;

FIG. 15. is a cross-sectional view of the acceleration which is taken along the line C-C of FIG. 14;

FIGS. 16A to 16C are plane views for explaining a process of forming the acceleration detector of the sixth embodiment;

FIGS. 17A to 17D are cross-sectional views for explaining the process of forming the detector, wherein FIG. 17A is taken along the line D-D of FIG. 16A, FIG. 17B is take along the line E-E of FIG. 16B, and FIG. 17D is taken along the line F-F of FIG. 16C;

FIG. 18 is a top plane view of a beam-type acceleration detector of a modification of the sixth embodiment;

FIG. 19 is a perspective view showing an adequate size of a beam-type acceleration detector from the viewpoint of resonance frequency thereof;

FIG. 20 is a perspective view showing an adequate size of a diaphragm-type acceleration detector from the viewpoint of resonance frequency thereof;

FIG. 21 is a perspective view of a diaphragm-type acceleration detector of the prior art;

FIG. 22 is a cross-sectional view of the acceleration detector which is taken along line G-G of FIG. 21;

FIG. 23 is a perspective view of a beam-type acceleration detector of the prior art;

FIG. 24 is a plane view illustrating an arrangement of resistance elements of the acceleration detector of FIG. 21;

FIGS. 25A to 25C are circuit diagrams showing the bridge configuration of resistance elements with respect to X-, Y- and Z-axes, respectively; and

FIGS. 26A to 26E are diagrams helpful for understanding stresses received resistance elements when acceleration is applied to a beam-type acceleration detector of the prior art.

DETAIL DESCRIPTIONS OF THE PREFERRED EMBODIMENTS

Preferred embodiments of an acceleration detector of the present invention are explained below. However, it should be noted that the present invention is not limited within the embodiments.

[First Embodiment]

A diaphragm-type acceleration detector of the first embodiment of the present invention are shown in FIGS. 1 and 2. The detector **1** is capable of sensitively detecting three-dimensional components of acceleration applied thereto independently with respect to three axes X-, Y- and Z- axes of an orthogonal coordinate system. The detector **1** is provided with a frame **10** defining an open space therein and having a top face **11** and a bottom face **12**, a bottom cover **20**, a thin-sheet resilient member **30**, a weight **40** hung from a center portion **31** of the resilient member **30** through a neck portion **41**, and a plurality of resistance elements **R** having a piezo resistance effect which are formed in the resilient member **30**. An air gap between the weight **40** and the bottom cover **20** is useful as an air damper for preventing a breakage of the detector **1** caused when a frequency of acceleration is equal to a resonance frequency of the detector. The resilient member **30** is fixed at its periphery to the top face **11** of the frame **10**. The X- and Y-axes are defined to extend in the general plane of the resilient member **30**. The neck portion **41** is connected with the center portion **31** of the resilient member **30** in such a manner as to cause an elastic deformation of the resilient member when the weight **40** is displaced with respect to the rectangular frame **10** by receiving acceleration. The frame **10**, the bottom cover **20**, resilient member **30** and the weight **40** are made of a semiconductor material such as a N-type silicon. The resistance elements **R** are formed in the resilient member **30** to be in an elongate shape thereof, as shown in FIG. 3. Impurities are added to a predetermined position of the resilient member **30** by, for example, a thermal diffusion method, to form a P-type silicon as the resistance elements **R**. An insulation layer (SiO_2) **80** is formed on the resilient member **30** for wiring a conductor pattern made of gold or aluminum thereon. For example, as shown in FIG. 3, a conductor pattern **60** formed on the insulation layer **80** extends to the resistance element **RZ3** through an opening **61** of the insulation layer. Electric resistance of the resistance elements **R** is varied in response to strain of the resistance elements accompanied with the elastic deformation of the resilient member **30**. As a result, acceleration is determined in accordance with the variation of the electric resistance of the resistance elements by an acceleration determining section (not shown).

The resistance elements **R** consisting of a first set of four resistance elements **RX1-RX4** for detecting a first component of acceleration with respect to the X-axis, a second set of four resistance elements **RY1-RY4** for detecting a second component of acceleration with respect to the Y-axis, and a third set of four resistance elements **RZ1-RZ4** for detecting a third component of acceleration with respect to the Z-axis. In this embodiment, the resistance elements **R** are arranged, as shown in FIG. 1. That is, the resistance elements **RX1** to **RX4** of the first set are arranged at positions adjacent to the opposite sides of the center portion **31** on both sides of the X-axis such that the longitudinal direction thereof is parallel to the X-axis. The resistance elements **RY1** to **RY4** of the second set are arranged at positions adjacent to the other opposite sides of the center portion **31** on both sides of the Y-axis such that the longitudinal direction thereof is parallel to the Y-axis. In addition, two resistance elements **RZ2** and **RZ3** of the third set are arranged on the X-axis at opposite positions adjacent to the frame **10**, and the other two resistance elements **RZ1** and **RZ4** are arranged on the Y-axis at the opposite positions adjacent to the frame.

The arrangement of the resistance elements **R** of the present invention is compared with that of resistance elements of the prior art from the viewpoint of the sensitivity of the acceleration detector **1**. For readily understanding the comparison, it is discussed only with respect to the resistance elements **RX1** to **RX4**. The acceleration detector of the prior art is the substantially same as the above explained detector except for the arrangement of the resistance elements.

As an arrangement of resistance elements **RX1** to **RX4** of the prior art, the resistance elements are aligned on the X-axis, as shown in FIG. 4A. When acceleration **G** is applied to a weight **40** of the detector in the X-axis direction, the resilient member **30** is elastically deformed, as shown in FIG. 26D, and stress is applied to each resistance element, as shown in FIG. 26E. As explained in "Disclosure of the Prior Art", the absolute value of the compressive or tensile stress received the resistance element adjacent to the frame **10** is equal to a half of that of the compressive or tensile stress received the resistance element adjacent to the center portion **31**. Therefore, in this case, the resistant elements **RX1**, **RX3** respectively receive tensile stresses σ and 2σ which are plus values, and the resistance elements **RX2** and **RX4** respectively receive compressive stresses 2σ and σ which are minus values. Electric resistance of the resistance elements **RX1** to **RX4** are respectively given by the following equations,

$$\mathbf{RX1} = \Omega \times (1 + \pi \ell \times \sigma) \qquad [1]$$

$$\mathbf{RX2} = \Omega \times (1 - \pi \ell \times 2\sigma) \qquad [2]$$

$$RX3 = \Omega \times (1 + \pi\ell \times 2\sigma) \quad [3]$$

$$RX4 = \Omega \times (1 - \pi\ell \times \sigma) \quad [4]$$

wherein Ω is electric resistance of the resistant elements measured without applying the acceleration **G**, and $\pi\ell$ is a piezo resistance coefficient. When a bridge circuit is formed by the resistance elements **RX1** to **RX4**, as shown in FIG. 25A, a bridge voltage is given by the following equation [5],

$$V = I \times (RX1 \times RX3 - RX2 \times RX4)/(RX1 + RX2 + RX3 + RX4) \quad [5]$$

wherein I is a predetermined current delivered from a power source to the bridge circuit. By substituting the above equations [1] to [4] for the equation [5], the bridge voltage obtained by the prior art's arrangement of the resistance elements is expressed by the following equation [6],

$$V = 1.5 \times \Omega \times \pi\ell \times \sigma \times I \quad [6].$$

On the other hand, the arrangement of the resistance elements **RX1** to **RX4** of the present invention is described above and shown in FIG. 4B. When the acceleration **G** is applied to the weight **40**, the resistant elements **RX2** and **RX4** receive a tensile stress 2σ, and the resistance elements **RX1** and **RX3** receive a compressive stress 2σ which is minus value. Therefore, electric resistance of the resistance elements **RX1** to **RX4** are given by the following equations [7] and [8],

$$RX1 = RX3 = \Omega \times (1 - \pi\ell \times 2\sigma) \quad [7]$$

$$RX2 = RX4 = \Omega \times (1 + \pi\ell \times 2\sigma) \quad [8].$$

By substituting the above equations [7] and [8] for the equation [5], the bridge voltage is expressed by the following equation [9],

$$V = 2 \times \Omega \times \pi\ell \times \sigma \times I \quad [9].$$

By comparing the equation [6] with the equation [9], it is concluded that the bridge voltage obtained by the arrangement of the resistance elements of the present invention is about 1.33 times as large as that obtained by the prior art's arrangement thereof. Though the above comparison is performed with respect to the X-axis, the same result is obtained with respect to the Y-axis. Therefore, by adopting the arrangement of the resistance elements of the present invention, an acceleration detector having an improved sensitively thereof with respect to the X- and Y-axes is obtained.

By the way, it is preferred that an electrode is mounted on a bottom surface of the weight **40** so as to be in a facing relation with the bottom cover **20**. When a voltage difference is applied between the electrode and the bottom cover **20** to develop an electrostatic force therebetween, it is possible to displace the weight **40** with respect to the frame **10** by the electrostatic force without applying acceleration to the weight **40** to thereby check whether the detector normally operates in a self-checking manner. For example, as shown in FIG. 5, a triangular electrode **70** is mounted on the bottom surface of the weight **40** to displace the weight along the X-, Y- and Z-axes simultaneously by an electrostatic force developed between the electrode **70** and the bottom cover **20**. For obtaining an increased electrostatic force, it is also possible to mount an auxiliary electrode (not shown) on a side face of the weight **40** adjacent to the triangular electrode **70**. In addition, it is preferred that four rectangular electrodes **71** are mounted, as shown in FIG. 6, to displace the weight **40** independently with respect to the X-, Y- and Z-axes.

[Second Embodiment]

An acceleration detector of the second embodiment is a substantially same as that of the first embodiment except that the resistance elements **R** are arranged, as shown in FIG. 7, in place of the arrangement of the resistance elements of FIG. 1. That is, the resistance elements **RX1** to **RX4** of the first set are arranged at positions adjacent to the opposite sides of the center portion **31** on both sides of the X-axis such that the longitudinal direction thereof is parallel to the Y-axis. The resistance elements **RY1** to **RY4** of the second set are arranged at positions adjacent to the other opposite sides of the center portion **31** on both sides of the Y-axis such that the longitudinal direction thereof is parallel to the X-axis. An

arrangement of the resistance elements **RZ1** to **RZ4** is the same as that of the first embodiment. When acceleration is applied to the weight **40** in the X-axis direction indicated by the arrow "Gx" of FIG. 7, in the Y-axis direction indicated by the arrow "Gy", and in the Z-axis direction indicated by "Gz" (an downward direction perpendicular to the paper plane in FIG. 7), a variation of electric resistance of each resistance element is listed on Table 1. On Table 1, plus (+) and minus (-) signs designate an increase in the electric resistance and a decrease in the electric resistance, respectively. In addition, "0" designates that no stress is applied to the resistance element.

TABLE 1

	RX1	RX2	RX3	RX4	RY1	RY2	RY3	RY4	RZ1	RZ2	RZ3	RZ4
Gx	-	+	-	+	0	0	0	0	0	+	+	0
Gy	0	0	0	0	+	-	+	-	+	0	0	+
Gz	+	+	+	+	+	+	+	+	+	-	+	-

[Third Embodiment]

An acceleration detector of the third embodiment is a substantially same as that of the second embodiment except that the resistance elements are arranged, as shown in FIG. 8, in place of the arrangement of the resistance elements of FIG. 7. That is, an arrangement of the resistance elements **RX1** to **RX4** and **RY1** to **RY4** is the same as that of the second embodiment. The resistance elements **RZ1** to **RZ4** are aligned on the X-axis.

[Fourth Embodiment]

An acceleration detector of the fourth embodiment is a substantially same as that of the first embodiment except that the resistance elements are arranged, as shown in FIG. 9, in place of the arrangement of the resistance elements of FIG. 1. That is, an arrangement of the resistance elements **RX1** to **RX4** and **RY1** to **RY4** is the same as that of the first embodiment. The resistance elements **RZ1** to **RZ4** are respectively arranged at positions adjacent to four sides of the center portion **31** on the X- and Y-axes such that the longitudinal direction of the resistance elements **RZ1** and **RZ2** is parallel to the Y-axis and the longitudinal direction of the resistance elements **RZ3** and **RZ4** is parallel to the X-axis.

Eventually, by adopting any one of the arrangements of the resistance elements of second to fourth embodiments, an acceleration detector having an improved sensitively thereof with respect to the X- and Y-axes is obtained.

[Fifth Embodiment]

A beam-type acceleration detector **1A** of the fifth embodiment of the present invention is shown in FIGS. 10A-10C, 11, and 12. The detector **1A** is provided with a bottom electrode **20A**, a frame **10A**, a thin-sheet resilient member **30A**, a weight **40A**, a plurality of resistance elements **R** having a piezo resistance effect, and a top electrode **50A**. The frame **10A** has an open space which is covered with the resilient member **30A** by fixing the periphery of the resilient member to a top face **11A** of the frame **10A**. The weight **40A** is hung down from a center portion **31A** of the resilient member **30A** through a neck portion **41A**. X- and Y-axes of a three-dimensional coordinate system are defined to extend in the general plane of the resilient member **30A**. The neck portion **41A** is connected with the center portion **31A** of the resilient member **30A** in such a manner as to cause an elastic deformation of the resilient member when the weight **40A** is displaced with respect to the frame **10A** by receiving acceleration. The resilient member **30A** is formed with four rectangular holes **32A** around the center portion **31A** so as to be shaped into a cross beam configuration. The resistance elements **R** are formed in the resilient member **30A** in accordance with the same method as the first embodiment. Any one of the arrangements of the resistance elements introduced in the first to fourth embodiments can be adopted in this embodiment, for example, as shown in FIG. 10B. The top electrode **50A** is fixed on the top face **11A** of the frame **10A** such that a rectangular projection **51A** and two triangular projections **52A** and **53A** formed on the top electrode **50A** are faced to an upper surface of the weight **40A** through the rectangular holes **32A** and are spaced away from the resilient

member 30A. These projections 51A, 52A and 53A are arranged as to give a generally triangular configuration as a whole, as shown in FIG. 10A or 12. The top electrode 50A is insulated from the frame 10A, resilient member 30A and the weight 40A by a first insulation layer 80A. The top electrode 50A is adapted to apply a voltage difference between the top electrode and the weight 40A to develop a first electrostatic force in order to displace the weight with respect to the frame 10A.

On the other hand, the bottom electrode 20A is fixed on a bottom face 12A of the frame 10A such that a bottom projection 21A formed on the bottom electrode is faced to a bottom surface of the weight 40A and is spaced away from the weight. The bottom projection 21A is in the form of a triangular configuration. The bottom electrode 20A is insulated from the frame 10A, the resilient member 30A and weight 40A by a second insulation layer 81A. The bottom electrode 20A is adapted to apply a voltage difference between the bottom electrode and the weight 40A to develop a second electrostatic force in order to displace the weight with respect to the frame 10A. The projections 51A to 53A and the bottom projection 21A are horizontally offset, as shown in FIG. 11, in such a relation that the first and second electrostatic forces are cooperative to displace the weight 40A along the X-, Y- and Z-axes simultaneously. Therefore, the weight 40A can be displaced by the electrostatic forces without applying acceleration to the weight 40A of the detector 1A, to thereby check whether the detector normally operates in a self-checking manner. In addition, a first air gap between the projections 51A to 53A and the weight 40A, and a second air gap between the bottom projections 21A and the weight 40A are useful as an air damper for preventing a breakage of the detector 1A when a frequency of acceleration is equal to a resonance frequency of the detector.

When the beam-type acceleration detector 1A adopts the arrangement of the resistance elements R of the present invention, an improved sensitivity of the detector with respect to X- and Y-axes is obtained.

[Sixth Embodiment]

A beam-type acceleration detector 1B of the sixth embodiment of the present invention is shown in FIGS. 13A-13C, 14, and 15. The detector 1B is provided with a bottom cover 20B, a frame 10B, a thin-sheet resilient member 30B, a weight 40B, a plurality of resistance elements R having a piezo resistance effect, and a top cover 50B. The frame 10B has an open space which is covered with the resilient member 30B by fixing the periphery of the resilient member to a top face 11B of the frame 10B. The weight 40B is hung down from a center portion 31B of the resilient member 30B through a neck portion 41B. The neck portion 41B is connected with the center portion 31B of the resilient member 30B in such a manner as to cause an elastic deformation of the resilient member when the weight 40B is displaced with respect to the frame 10B by receiving acceleration. The resilient member 30B is formed with four rectangular holes 32B around the center portion 31B so as to be shaped into a cross beam configuration. X- and Y-axes of a three-dimensional coordinate system are defined to extend in the general plane of the resilient member 30B. Any one of the arrangements of the resistance elements introduced in the first to fourth embodiments can be adopted in this embodiment, for example, as shown in FIG. 13B. The resistance elements R are formed in the resilient member 30B in accordance with the same method as the first embodiment. The weight 40B is formed with four rectangular projections 42B which project respectively into the rectangular holes 32B of the resilient member 30B in such a manner that a top surface of each projection is flush with a top surface of the resilient member. In addition, a corner of each projection 42B is integrally merged with the center portion 41B by a joint portion 43B. A rectangular electrode 70B and two triangular electrodes 71B and 72B are mounted on the projections 42B so as to give a generally triangular configuration as a whole, as shown in FIG. 14. A first insulation layer 80B is formed on the projections 42B, the resilient member 30B and the joint portion 43B. The joint portion 43B is useful to form on the first insulation layer 80 B a conductor pattern 60B made of gold or aluminum which extends from each of the electrodes 70B to 72B to a bonding pad 62B.

On the other hand, a bottom electrode 73B is mounted on a bottom surface of the weight 40B, as shown in FIG. 15. The bottom electrode 73B is in the form of a triangular configuration. Since each of the electrodes 70B to 72B extends to the weight 40B through an opening 61B of the first insulation layer 80B, a voltage applied to the electrodes 70B to 72B can be also applied to the bottom electrode 73B.

A process of manufacturing parts of the acceleration detector 1B, that is, the frame 10B, resilient member 30B and the electrodes 70B to 72B on the weight 40B, is shown in FIGS. 16A to 16C and 17A-17D. Firstly, a pattern of the frame 10B, four rectangular projections 42B, the neck portion 41B and joint portions 43B is formed in a N-type silicon substrate by an etching method with the use of potassium hydroxide, as shown in FIGS. 16A and 17A. Subsequently, a N-type silicon wafer is directly jointed on the pattern, and ground to obtain the resilient member 30B having a predetermined thickness T and a mirror-

polished surface thereof, as shown in FIGS. 16B and 17B. A clearance between the weight **40B** and frame **10B** is formed by carrying out the etching method from the bottom surface of the silicon substrate, as shown in FIG. 17C. Then, slits **S** extending between the projections **42B** and the frame **10B** and between the projections and the resilient member **30B** are formed by a reactive ion etching method, as shown in FIG. 16C. A silicon oxide (SiO_2) layer is formed as the first insulation layer **80B** on top surfaces of the projections **42B**, the resilient member **30B** and the top face **11B** of the frame **10B**. The resistance elements **R** having a piezo resistance effect are formed in the resilient member **30B** prior to the formation of the first insulation layer **80B**. The rectangular and triangular electrodes **70B** to **72B** made of gold are formed on the first insulation layer **80B** on the rectangular projections **42B**, as shown in FIG. 17D. It is to be noted that the above described process is shown as merely one example, and therefore it is possible to adopt another process for manufacturing the acceleration detector of the present invention.

The top cover **50B** is fixed on the top face **11B** of the frame **10B** such that the electrodes **70B** to **72B** are spaced away from a bottom surface of the top cover. Similarly, the bottom cover **20B** is fixed on a bottom face **12B** of the frame **10B** such that the bottom electrode **73B** is spaced away from a top surface of the bottom cover **20B**, as shown in FIG. 15. The top and bottom covers **50B** and **20B** are respectively insulated from the frame **10B**, the resilient member **30B** and weight **40B** by first and second insulation layers **80B** and **81B**. The rectangular and triangular electrodes **70B** to **72B** are adapted to apply a voltage difference between the electrodes and the top cover **50B** to develop a first electrostatic force in order to displace the weight **40B** with respect to the frame **10B**. The bottom electrode **73B** is adapted to apply a voltage difference between the lower electrode and the bottom cover **20B** to develop a second electrostatic force in order to displace the weight **40B** with respect to the frame **10B**. The electrodes **70B** to **72B** and the bottom electrodes **73B** are horizontally offset, as shown in FIG. 14, in such a relation that the first and second electrostatic forces are cooperative to displace the weight **40B** along the X-, Y- and Z-axes simultaneously. Therefore, the weight **40B** can be displaced by the electrostatic forces without applying acceleration thereto, to thereby check whether the acceleration detector **1B** normally operates in a self-checking manner. For obtaining an increased electrostatic force, it is preferred that a side electrode (not shown) is mounted on at least one of two side faces of the weight **40B** which are adjacent to the triangular configuration of the electrodes **70B** to **72B**. In addition, a first air gap between the electrodes (**70B** to **72B**) and the top cover **50B**, and a second air gap between the bottom electrode **73B** and the bottom cover **20B** are useful as an air damper for preventing a breakage of the detector when a frequency of acceleration is equal to a resonance frequency of the detector **1B**.

Eventually, when the beam-type acceleration detector **1B** adopts the arrangement of the resistance elements **R** of the present invention, an improved sensitivity of the detector with respect to X- and Y-axes is obtained.

As a modification of the acceleration detector **1B** of the sixth embodiment, it is preferred that four rectangular electrodes **74B** to **77B** are formed on the rectangular projections **42B** in place of the rectangular and triangular electrodes **70B** to **72B**, as shown in FIG. 18. For example, when a voltage difference is applied between the electrodes (**74B** and **75B**) and the top cover **50B**, the weight **40B** can be displaced with respect to the X-axis. When a voltage difference is applied between the electrodes (**74B** and **76B**) and the top cover **50B**, the weight **40B** can be displaced with respect to the Y-axis. An electrostatic force developed for displacing the weight **40B** with respect to the X- or Y-axis in this modification is one and half times or more as large as the electrostatic force developed in the sixth embodiment. In addition, when a voltage difference is applied between all of the rectangular electrodes (**74B** to **77B**) and the top cover **50B**, the weight **40B** can be displaced with respect to the Z-axis. In this case, an electrostatic force developed between the electrodes **74B** to **77B** and the top cover **50B** is twice as large as that developed between the electrodes **70B** to **72B** and the top cover. Therefore, the acceleration detector of this modification is capable of displacing the weight **40B** independently with respect to X-, Y- and Z-axes by the electrostatic force developed between the selected electrodes and top cover **50B**.

By the way, it is preferred that each of the acceleration detectors described in the first to sixth embodiments is designed such that resonance frequencies of the acceleration detector with respect to the X- and Y-axes are equal to the resonance frequency thereof with respect to the Z-axis. Frequency resonances (**frx** to **frz**) of an acceleration detector are respectively is generally expressed by the following equations [10] to [12],

$$\mathbf{frx} = (1/2\pi) \times \{g/(m \times Cx)\}^{1/2} \qquad [10]$$

$$\mathbf{fry} = (1/2\pi) \times \{g/(m \times Cy)\}^{1/2} \qquad [11]$$

$$frz = (1/2\pi) \times \{g/(m \times Cz)\}^{1/2} \quad [12]$$

wherein "**g**" is gravitational acceleration, "**m**" is the weight of a weight of the detector and "**Cx**", "**Cy**" and "**Cz**" are compliances with respect to the X-, Y- and Z-axes, respectively. Therefore, when a design of the acceleration detector is determined such that the compliances **Cx** and **Cy** are equal to the compliance **Cz**, a common resonance frequency is obtained with respect to the three axes. For example, in case of a beam-type acceleration detector, it is preferred to design the detector, as shown in FIG. 19. In this case, the resonance frequency of the detector is 3300Hz. On the other hand, in case of a diaphragm-type acceleration detector, it is preferred to design the detector, as shown in FIG. 20. In this case, the resonance frequency of the detector is 4400 Hz. In FIGS. 19 and 20, a thickness of a resilient member of each detector is 7 μm, and a unit of each size is millimeter (mm). Even if the thickness of the resilient member is varied, the following relation is maintained, that is

$$frx = fry = frz.$$

Therefore, when the acceleration detector is designed, as shown in FIG. 19 or 20, it is possible to determine a practical frequency zone of the acceleration detector without using an electrical filter for determining the frequency zone.

Claims

1. An acceleration detector (1, 1A, 1B) for independently detecting three-dimensional components of acceleration with respect to the X-, Y- and Z-axes of an orthogonal coordinate system, comprising
   a thin-sheet resilient member (30, 30A, 30B) joined at its periphery to a frame (10, 10A, 10B), said X- and Y-axes being defined to extend in the general plane of said resilient member;
   a weight (40, 40A, 40B) connected to a center portion of said resilient member (30, 30A, 30B) to cause an elastic deformation of said resilient member when subjected to acceleration;
   a plurality of piezo resistance elements (R) formed at said resilient member (30, 30A, 30B) and comprising a first set of resistance elements (RX1-RX4) for detecting a first component of said acceleration with respect to said X-axis, a second set of resistance elements (RY1-RY4) for detecting a second component of said acceleration with respect to said Y-axis, and a third set of resistance elements (RZ1-RZ4) for detecting a third component of said acceleration with respect to said Z-axis, wherein all of said resistance elements of said first and second sets are disposed within an inner area of said resilient member (30, 30A, 30B) immediately adjacent said center portion (31, 31A, 31B), said inner area being capable of causing a larger elastic deformation than an outer area of said resilient member adjacent said frame (10, 10A, 10B) when said weight (40, 40A, 40B) is displaced by said acceleration.

2. The detector of claim 1, wherein said third set includes two resistance elements (RZ2, RZ3) arranged at opposite positions of said outer area on said X-axis and two resistance elements (RZ1, RZ4) arranged at opposite positions of said outer area on said Y-axis.

3. The detector of claim 1, wherein said third set includes four resistance elements (RZ1-RZ4) aligned on one of said X- and Y-axes.

4. The detector of claim 1, wherein said third set includes four resistance elements (RZ1-RZ4) arranged within said inner area.

5. The detector of any one of claims 1 to 4, wherein said resilient member (30A) is formed with four rectangular holes (32A) around said center portion (31A) so as to be shaped into a cross beam configuration; and further including:
   an upper cover (50A) fixed on the top face (11A) of said frame (10A) in a spaced relation to said resilient member, said upper cover provided on its bottom surface with at least one upper electrode (51A-53A) projecting towards the adjacent holes (32A) in said resilient member (30A) in a facing relation to the upper end of said weight (40A); and
   said upper electrode (51A-53A) being adapted to apply a voltage difference between said upper electrode and said weight (40A) to develop an electrostatic force in order to displace said weight with respect to said frame (10A) for determination of the acceleration (1A) in a self-checking manner.

6. The detector of claim 5, further including
   a lower cover (20A) fixed on the bottom face (12A) of said frame (10A) in a spaced relation to said weight (40A); and
   said lower cover (20A) being provided with a lower electrode (21A) in facing relation to the bottom of said weight (40A), said lower electrode being adapted to apply a voltage difference between said lower electrode and said weight to develop an electrostatic force in order to displace said weight with respect to said frame.

7. The detector of claim 6, wherein said upper electrode (51A-53A) comprises a rectangular plate (51A) and two triangular plates (52A,53A) which are so arranged as to give a generally triangular configuration to said upper electrode, and said lower electrode (21A) is in the form of a triangular configuration, said upper and lower electrodes being horizontally offset such that the resulting two electrostatic forces are cooperative to displace said weight (40A) along said X-, Y-, and Z-axes simultaneously.

8. The detector of any one of claims 1 to 4, wherein said resilient member (30B) is formed with four rectangular holes (32B) around said center portion (31B) so as to be shaped into a cross beam configuration; and further including:
   an upper cover (50B) fixed on the top face (11B) of said frame (10B) in a spaced relation to said resilient member,
   said weight (40B) formed integrally with four projections (42B) which project respectively into said rectangular holes (32B) in said resilient member (30B) in such a manner that a top face of each projection (42B) is flush with the top surface of said resilient member, a corner of each said projection merging integrally into said center portion (31B) of said resilient member by way of a joint portion (43B);
   at least one of said projections (42B) carrying an upper electrode (70B-72B) which is adapted to apply a voltage difference between said upper electrode and said upper cover (50B) to develop an electrostatic force in order to displace said weight (40B) with respect to said frame (10B) for determination of the acceleration in a self-checking manner; and
   said joint portion (43B) forming thereon a conductor leading from said upper electrode to a voltage supply for applying said voltage difference.

9. The detector of claim 8, further including:
   a lower cover (20B) fixed on the bottom face (12B) of said frame (10B) in a spaced relation to said weight (40B); and
   said weight (40B) being provided on its bottom with a lower electrode (73B), said lower electrode being adapted to apply a voltage difference between said lower electrode and said lower cover (20B) to develop an electrostatic force in order to displace said weight (40B) with respect to said frame (10B).

10. The detector of claim 9, wherein said upper electrode (70B-72B) comprises a rectangular plate (70B) and two triangular plates (71B,72B) which are so arranged as to give a generally triangular configuration to said upper electrode, and said lower electrode (73B) is in the form of a triangular configuration, said upper and lower electrodes being horizontally offset such that the resulting two electrostatic forces are cooperative to displace said weight (40B) along said X-, Y-, and Z-axes simultaneously.

FIG. 1

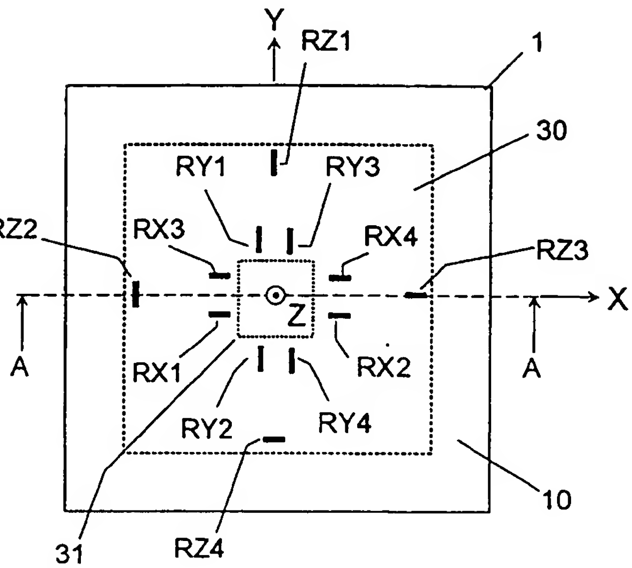


FIG. 2

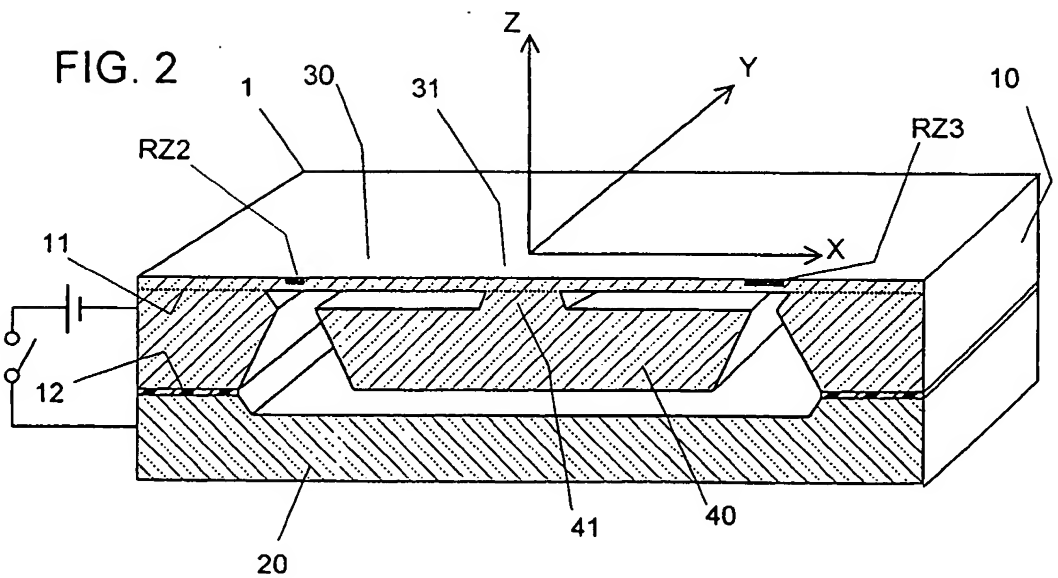


FIG. 3

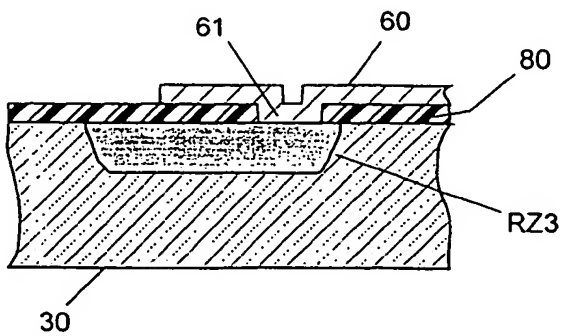


FIG. 4A

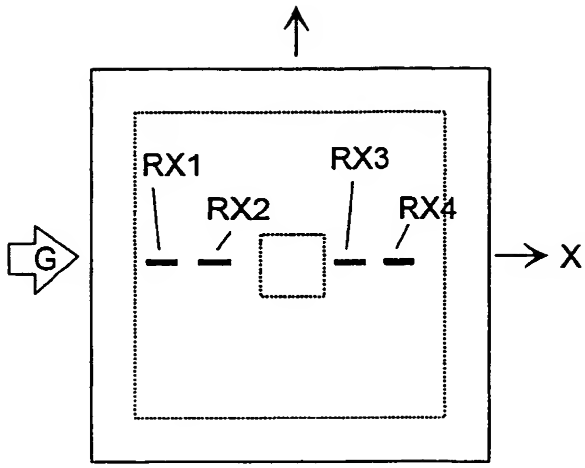


FIG. 4B

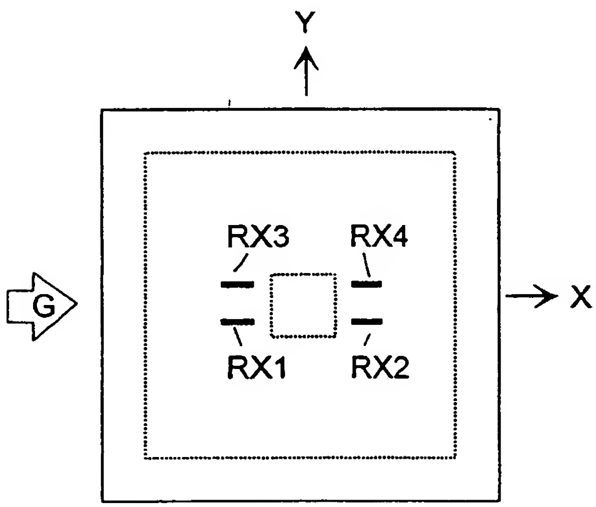


FIG. 5

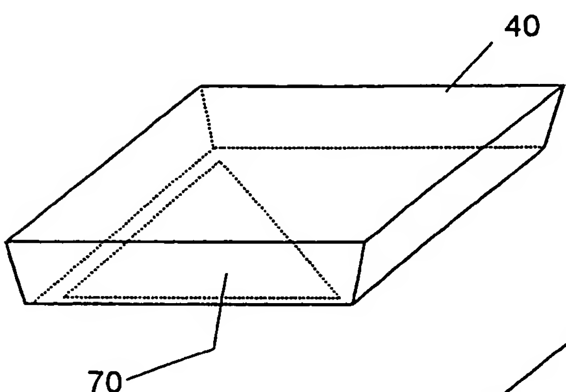


FIG. 6

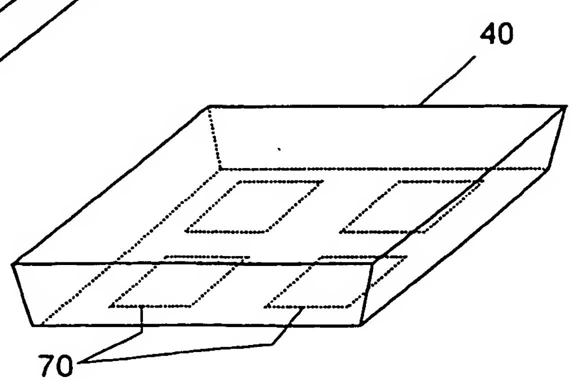
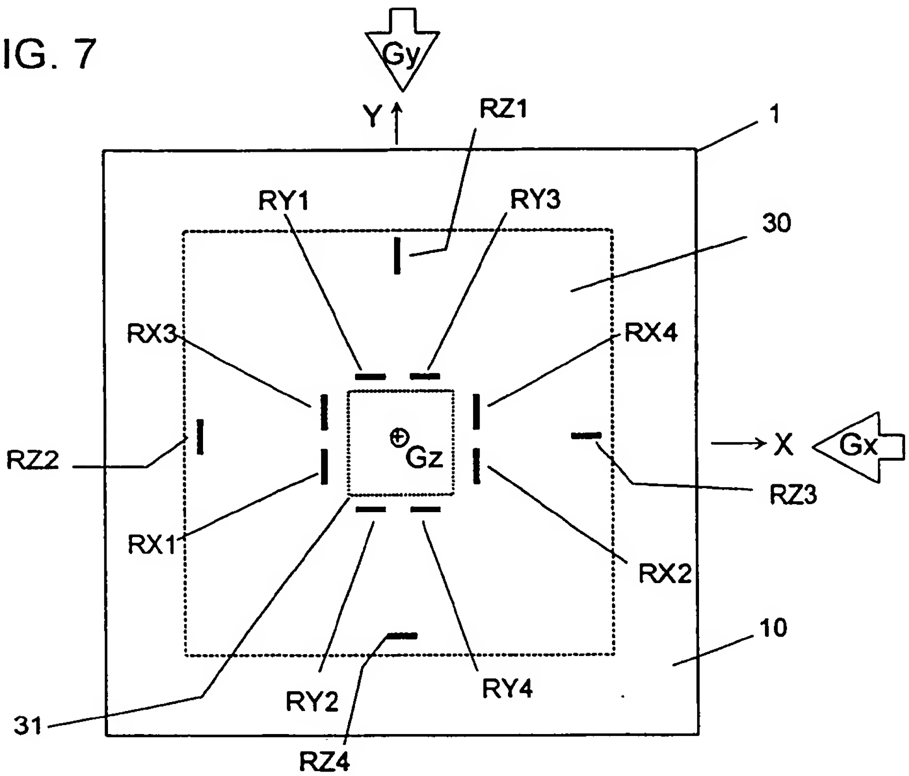


FIG. 7



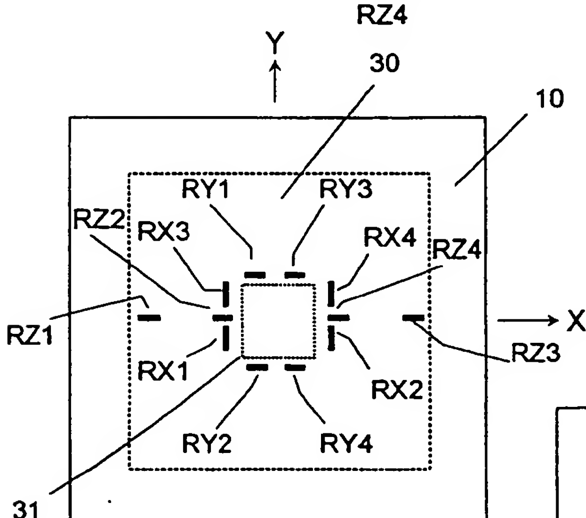


FIG. 8

FIG. 9

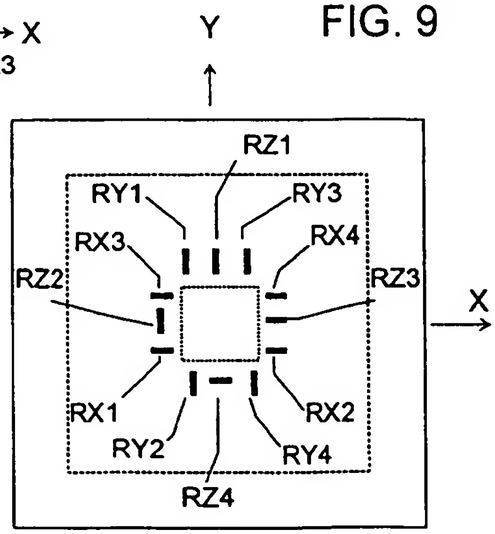


FIG. 10A

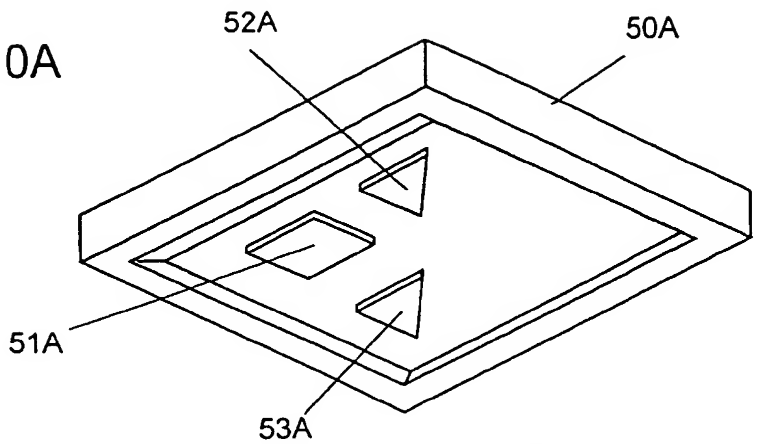


FIG. 10B

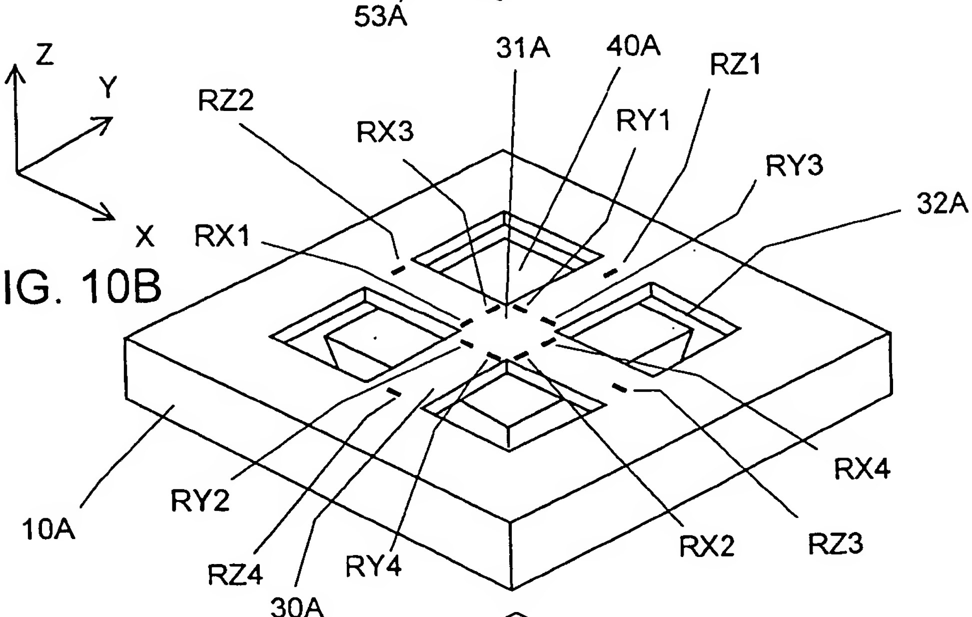


FIG. 10C

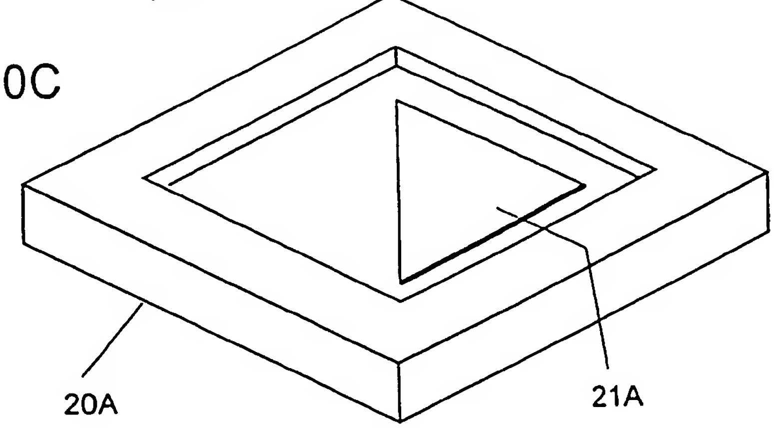


FIG. 11

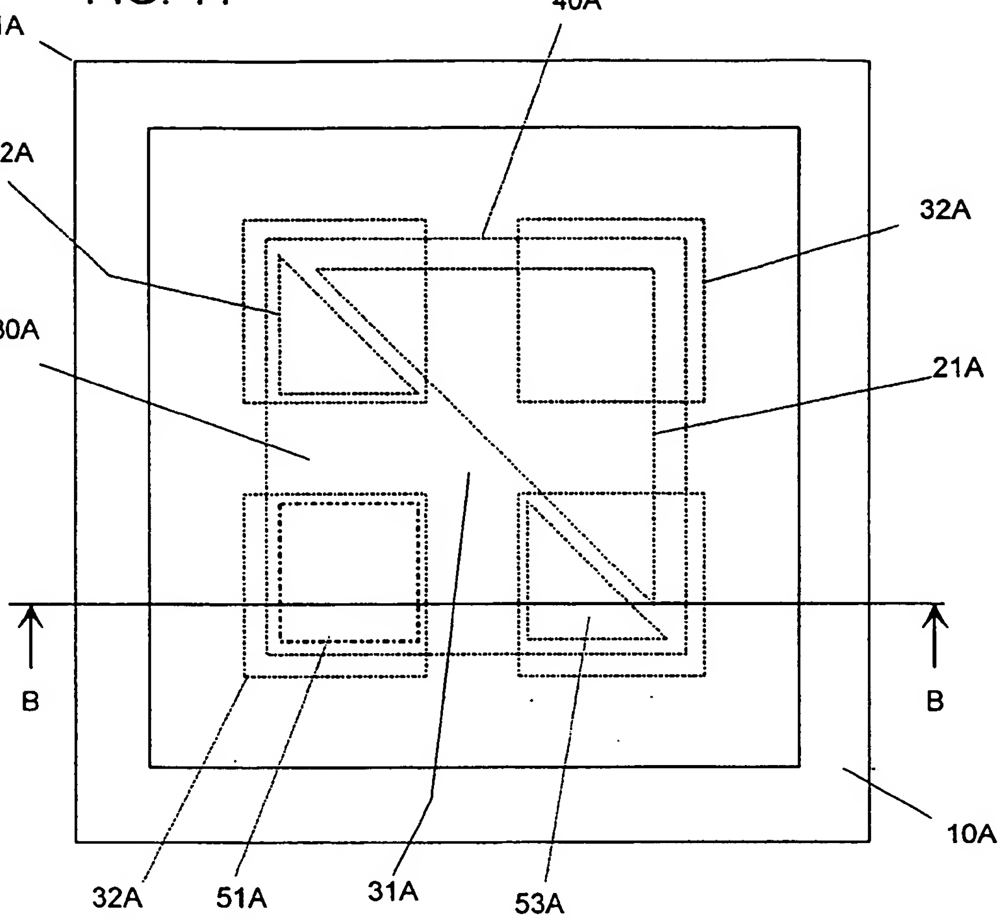
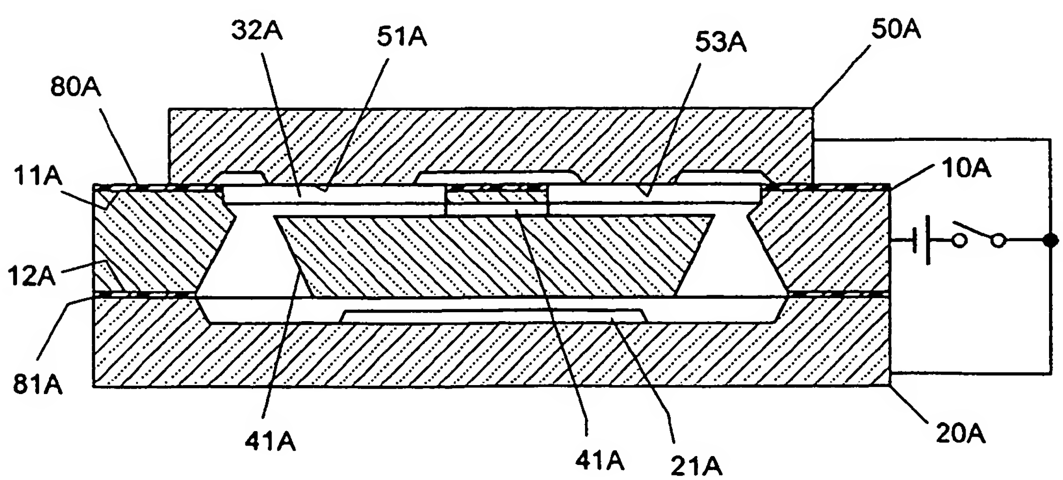

1A
40A
52A
32A
30A
21A
B
B
10A
32A
51A
31A
53A

FIG.12


32A
51A
53A
50A
80A
10A
11A
12A
81A
41A
41A
21A
20A

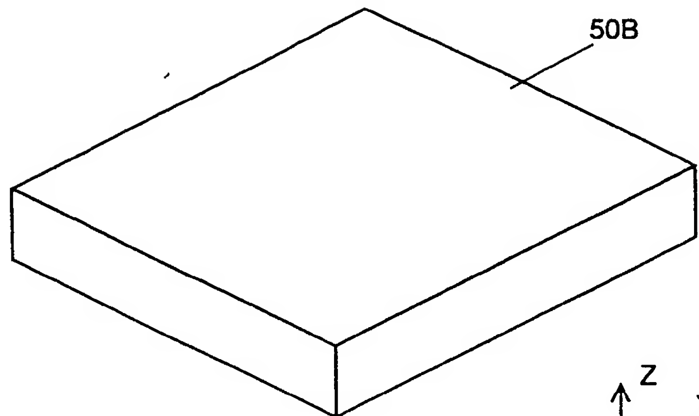


FIG. 13A

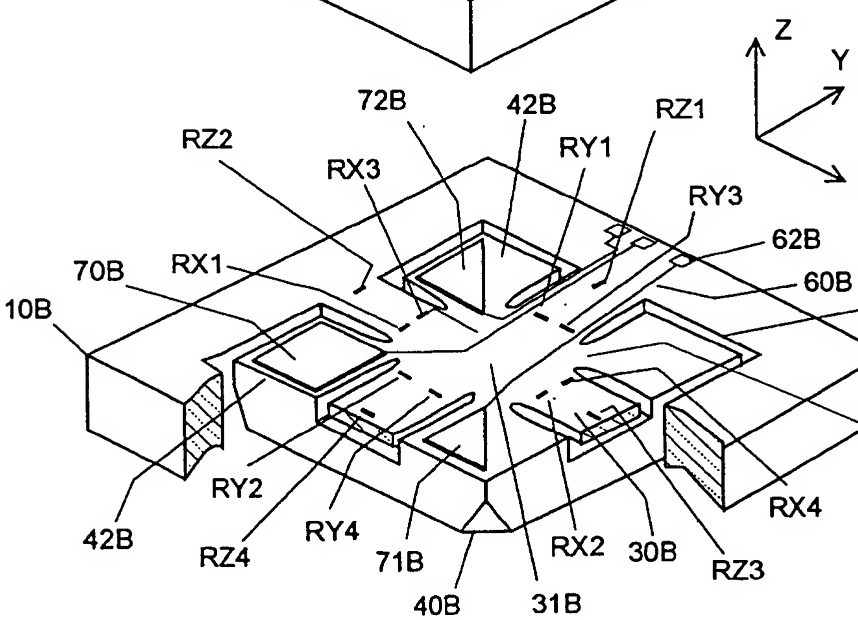


FIG. 13B

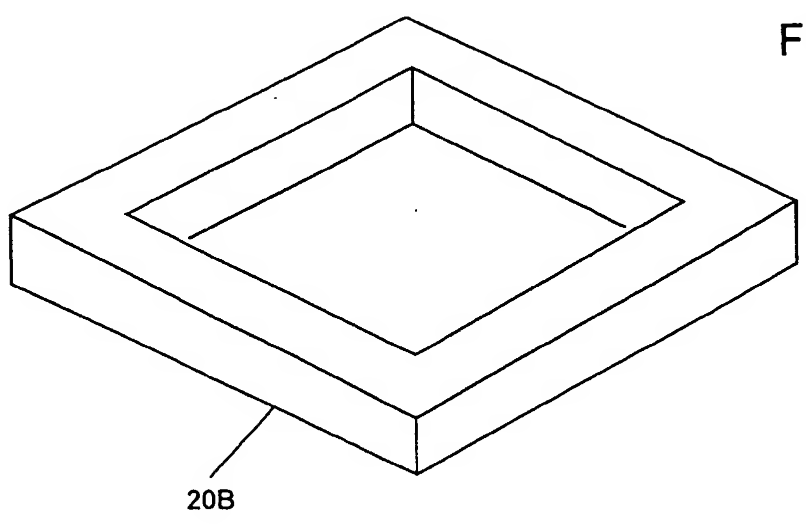


FIG. 13C

FIG. 14

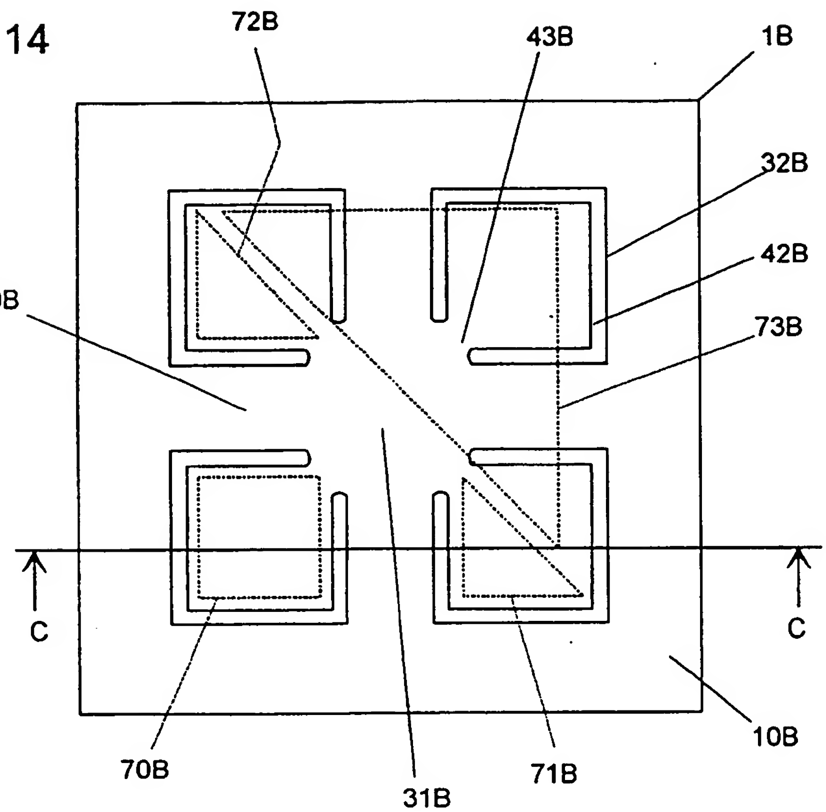

72B
43B
1B
32B
42B
30B
73B
C
C
10B
70B
31B
71B

FIG. 15

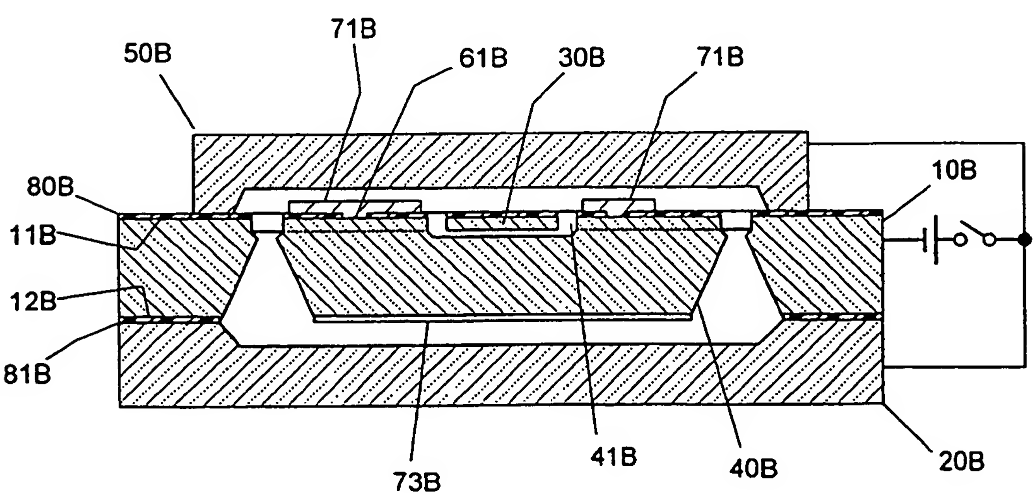

71B
50B
61B
30B
71B
80B
10B
11B
12B
81B
73B
41B
40B
20B

FIG. 16A

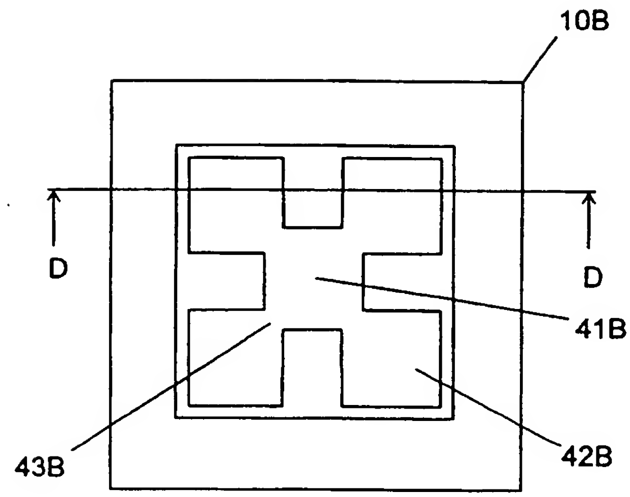


FIG. 16B

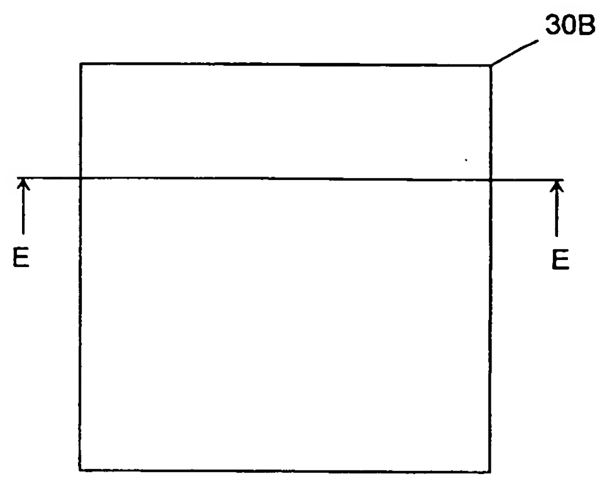


FIG. 16C

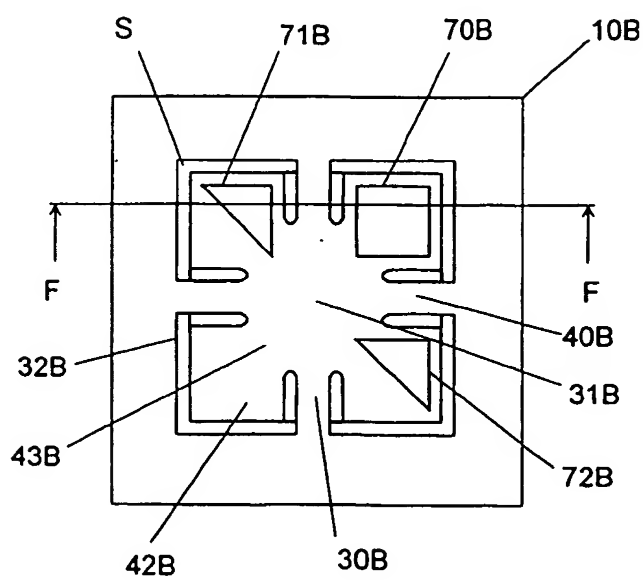


FIG. 17A

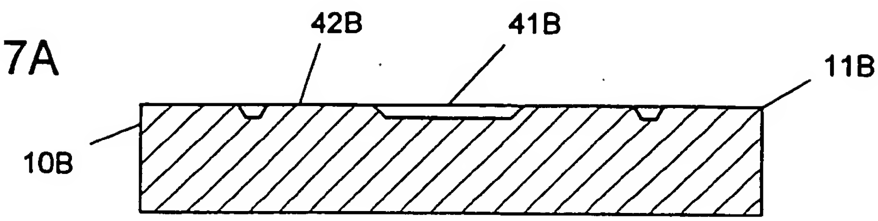


FIG. 17B

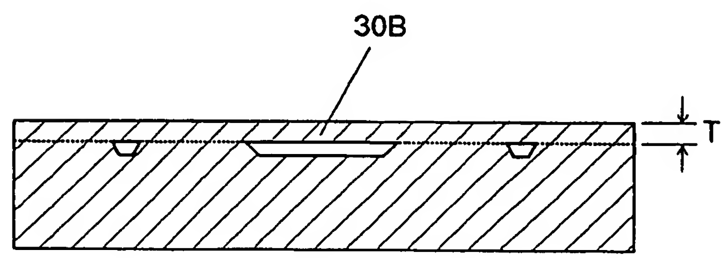


FIG. 17C

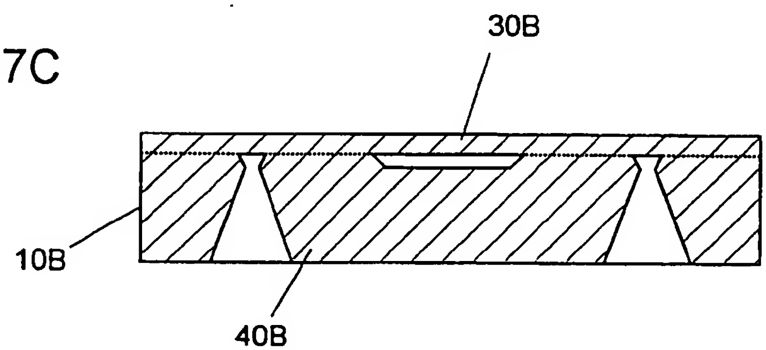


FIG. 17D

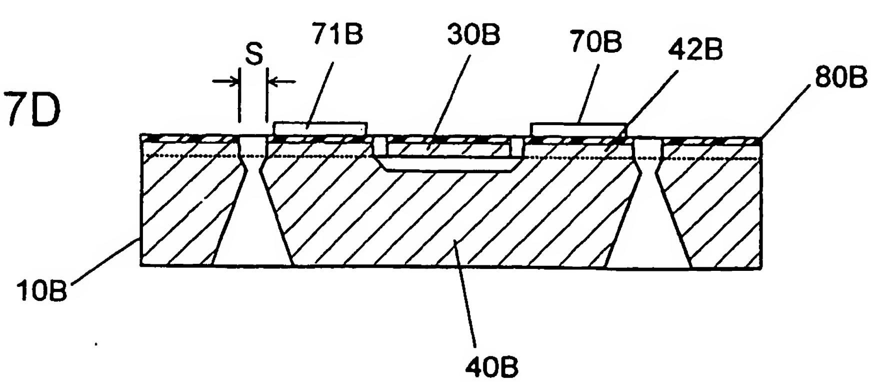


FIG. 18

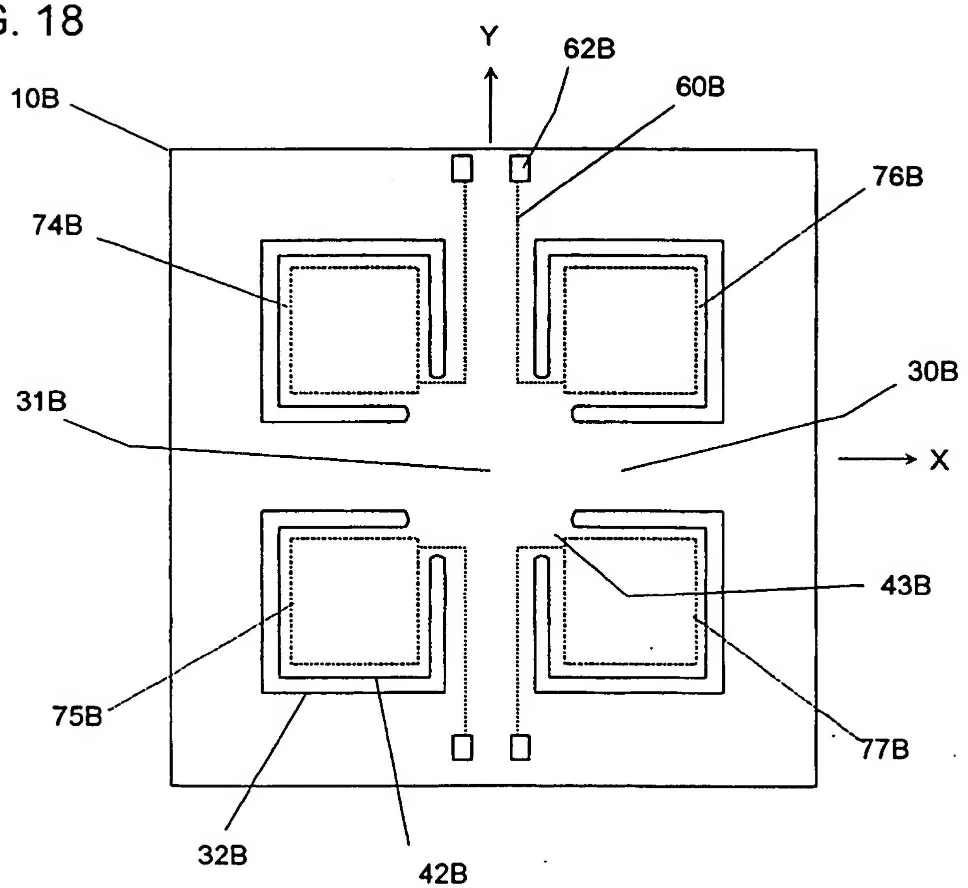


FIG. 19

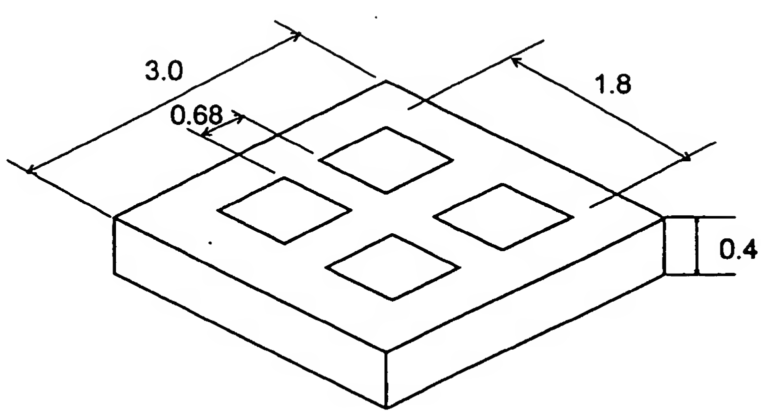


FIG. 20

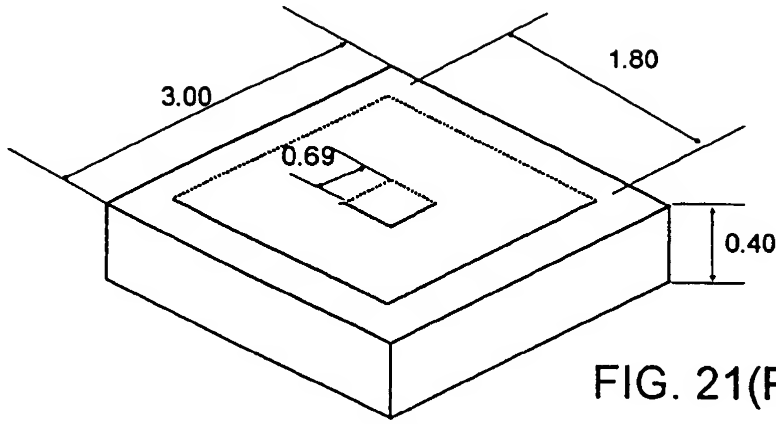


FIG. 21(PRIOR ART)

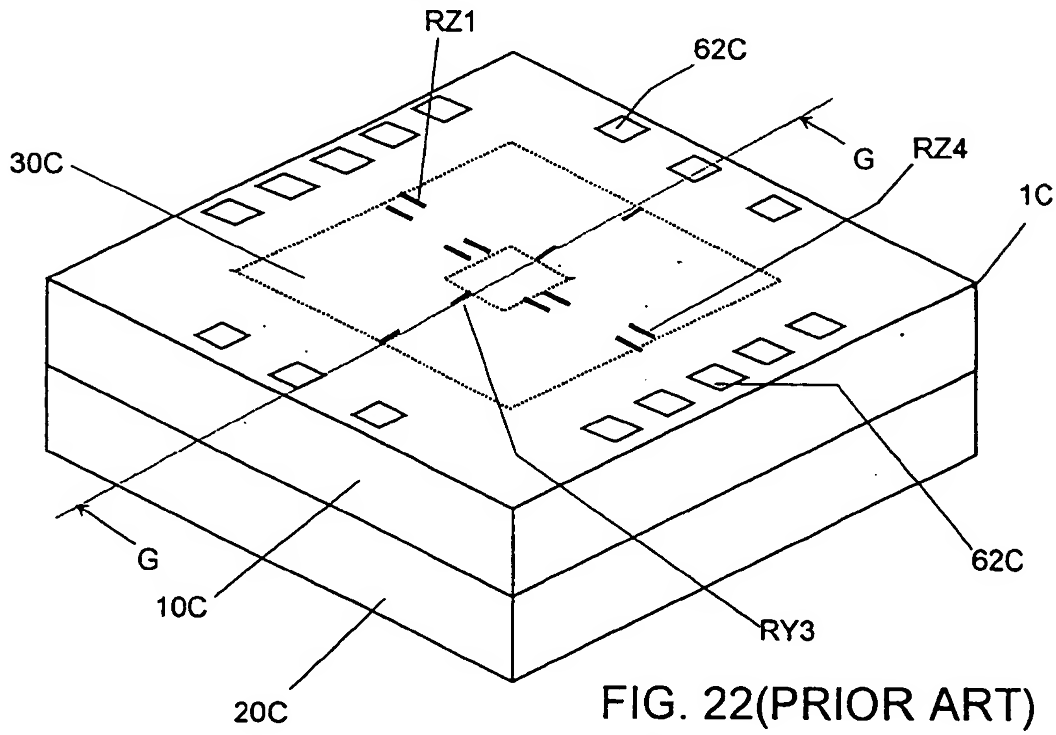


FIG. 22(PRIOR ART)

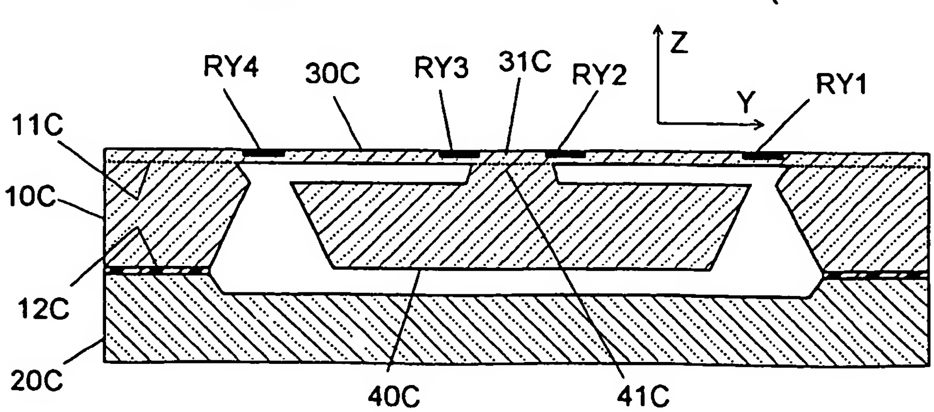


FIG. 23 (PRIOR ART)

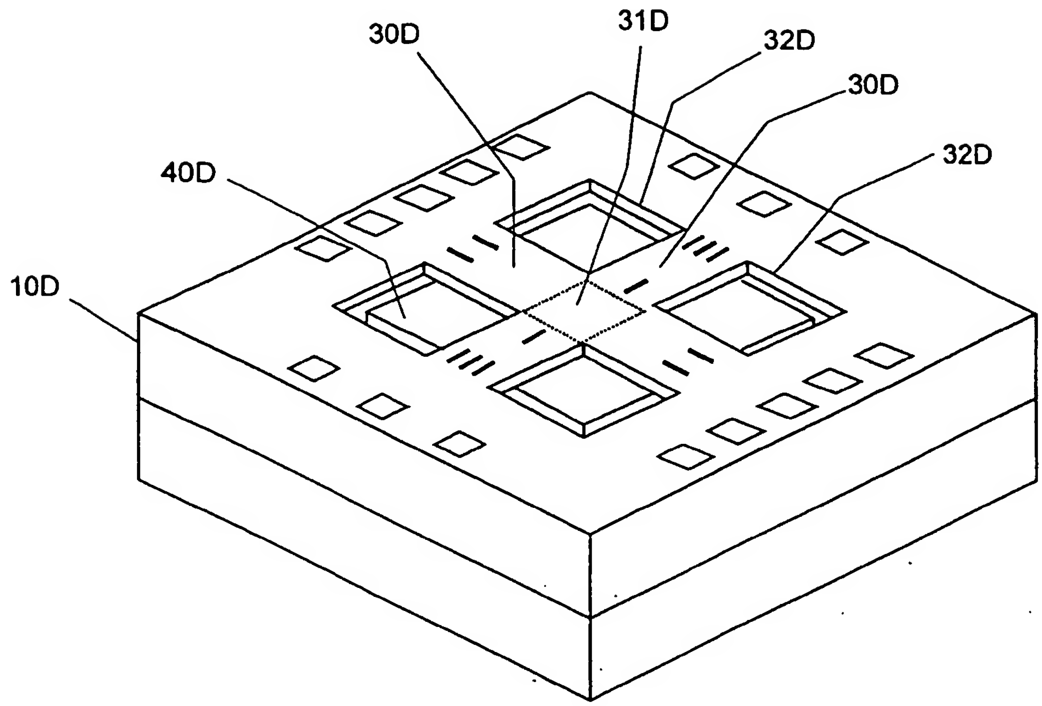


FIG. 24 (PRIOR ART)

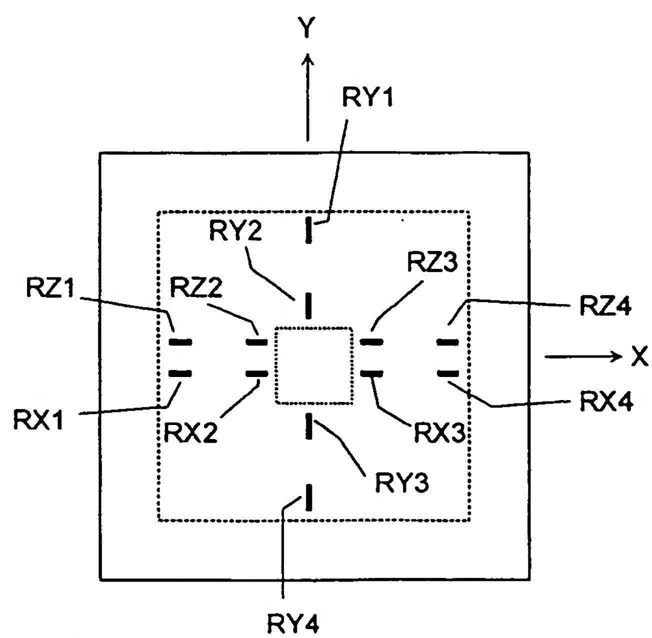


FIG. 25A
(PRIOR ART)

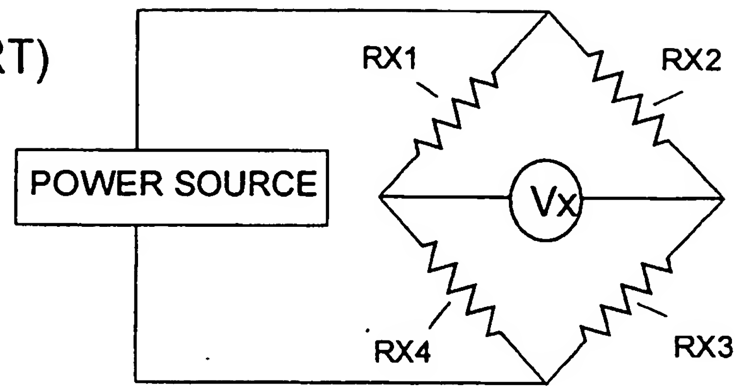


FIG. 25B
(PRIOR ART)

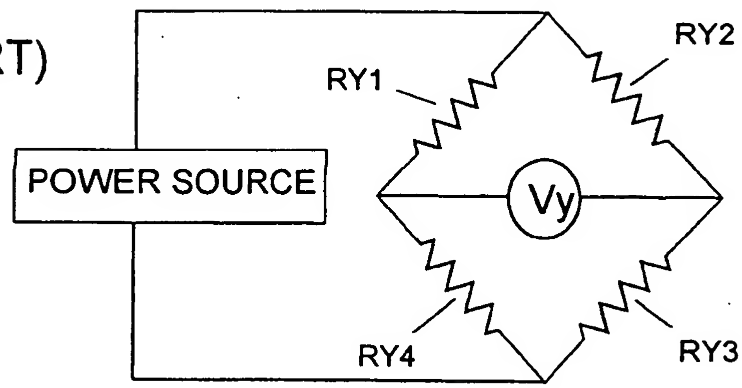
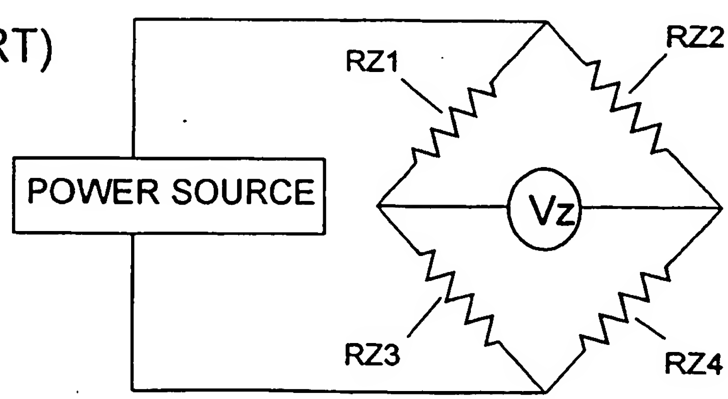


FIG. 25C
(PRIOR ART)



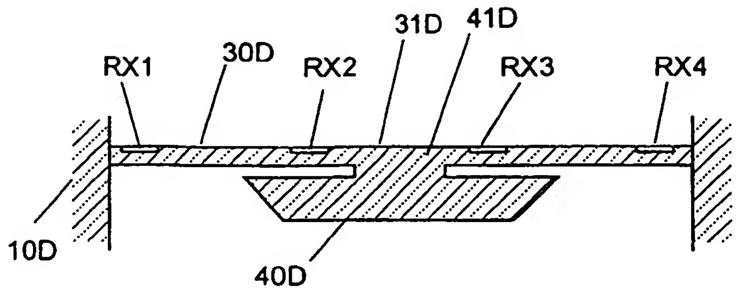


FIG. 26A
(PRIOR ART)

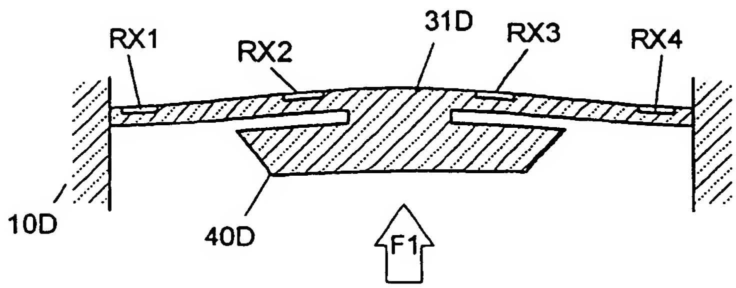


FIG. 26B
(PRIOR ART)

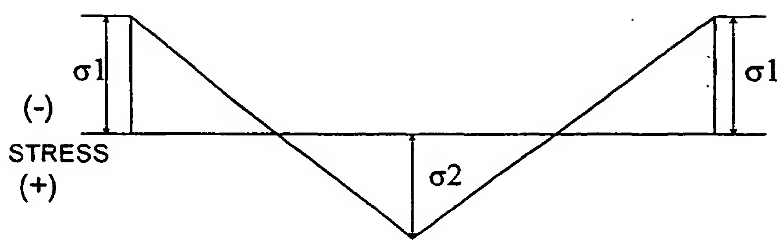


FIG. 26C
(PRIOR ART)

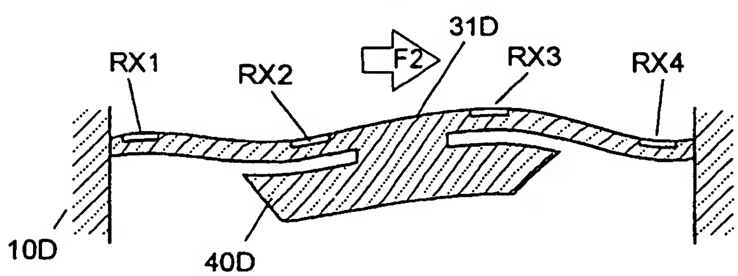


FIG. 26D
(PRIOR ART)

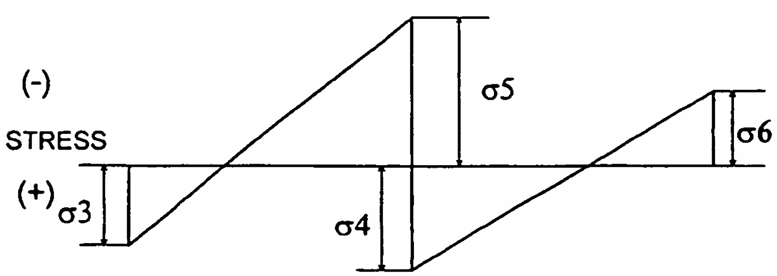


FIG. 26E
(PRIOR ART)

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 94 10 7635

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.5)
A	EP-A-0 461 265 (WACOH CORPORATION) * page 11, line 38 - line 50 * * page 17, line 37 - page 18, line 33; figures 1,2,4,5,17-19 * ---	1,3,5,6, 8,9	G01P15/00 G01P21/00
A	GB-A-1 300 118 (FERRANTI LIMITED) * page 2, line 27 - line 38; figure 1 * ---	1	
A	US-A-5 081 867 (KEIZO YAMADA) * column 5, line 3 - line 13; figure 6 * ---	1,5,8	
A D	US-A-4 967 605 (KAZUHIRO OKADA) * column 4, line 65 - column 5, line 10; figures 1-12 * -----	1,3	

TECHNICAL FIELDS SEARCHED (Int.Cl.5)

G01P

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	13 September 1994	Hansen, P

CATEGORY OF CITED DOCUMENTS

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